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FINAL REPORT
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During the grant period, the LAWS instrument was deselected from EOS, but several other possible configurations of the instrument are under active consideration by the Working Group on Space-Based Lidar Winds. As will be discussed below, these configurations vary widely in their orbital parameters, and it was difficult to continue our diagnostic Observing System Simulation Experiments (OSSEs). Indeed, some of the new configurations would not allow us to do what we initially proposed, the study of tropical cyclones using LIDAR winds. As a result, after briefly reviewing our OSSE results in this section, we will describe studies that focused on what scientific problems the newly proposed Lidar instruments could be used to solve.

The general procedure for diagnostic OSSEs was as follows: (i) choose a storm of interest and analyze all available data from the storm; (ii) use these analyses to construct a simulated Lidar wind data set; (iii) impose instrument and other forms of error on the simulated Lidar data; (iv) re-analyze using the Lidar data only and compute differences from the control analysis in parameters which we previously had found to be important in the behavior of the tropical cyclone.

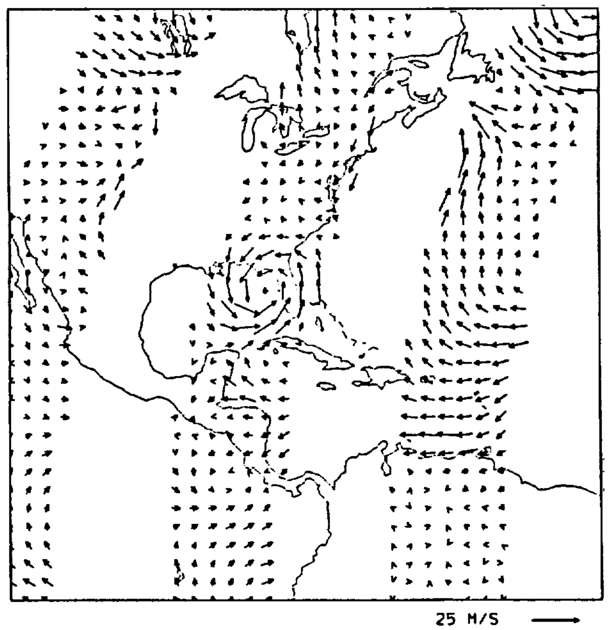
These "diagnostic OSSEs" differed from the prognostic OSSEs that were done by other committee members. The benefit of the diagnostic OSSE is its ability to evaluate whether Lidar wind data can be used for traditional meteorological studies, independent of the need for assimilation of Lidar data within numerical models. This consideration is particularly important in tropical cyclone studies because numerical models do not simulate them well over open ocean. Diagnostic use of wind Lidar data from a polar orbiter requires use of multiple swaths of data that are taken 90 min apart. Previous studies showed that errors introduced by the 1.5-3 hour time difference among swaths were not significant, and winds in the tropical cyclone environment were accurately reproduced using only simulated Lidar winds.

A more significant variable was swath width. Wide swaths (> 1000 km) allow most or all of the tropical cyclone circulation to be included in a single swath. Even if the swath were not centered on the tropical cyclone, our earlier studies showed that missing winds in the storm environment could be recovered by objectively analyzing simulated Lidar winds where they occurred. Large swaths occur with high orbits such as 705 and 824 km. At these levels the data coverage can be as large as 67%. Figure 1 (next page) shows simulated swaths on 0000 UTC 1 September 1985 during Hurricane Elena assuming 824 km altitude.

For much lower altitudes such as 350 km, swath widths (and thus percent data coverage) are much smaller. At these altitudes, features on the scale of tropical cyclones cannot be captured sufficiently. The currently proposed wind Lidar mission platform altitudes range from 350 km (for a "small-sat" mission) to 824 km (for a joint NOAA-DOD platform). Given the uncertainty regarding placement of the instrument, efforts have been made to broaden our studies so that useful data could be obtained regardless of orbital parameters, Laser power, and the many other variables that remain to be specified.

Our research centered on the subtropical Atlantic Ocean. The vast majority of Atlantic and eastern Pacific tropical cyclones are thought to develop from synoptic scale waves that cross the subtropical Atlantic from their origin in Africa. The nature of these "easterly waves" (so named because they propagate within an east-to-west current) is extremely poorly understood, however, because (i) wind data is almost completely lacking, and (ii) global numerical models do not reproduce them well [which, of course, is related to (i)]. What is known is the following: the waves are synoptic scale and develop over Africa in a region of "reversed" temperature gradient, with hot air to the north (over the Sahara) and cool air to the south over the equatorial rain forests. Wave development is intimately related to baroclinic energy sources, i.e., relies on the existence of the temperature gradient. Over water, however, the temperature gradient vanishes and the easterly wave dynamics is largely unknown.

Figure 1. Simulated Lidar wind data for 0000 UTC 1 September 1985. Hurricane Elena is present over the northeast Gulf of Mexico.



An example of the consequences of this can be shown in the following study we recently completed. The goal of the study was to understand the reason that the eastern Pacific experiences active and inactive periods of tropical cyclogenesis. Table 1 (below) indicates the number of storms during four of these 10-12 day periods during 1991.

The time-mean fields during Active 1 and Inactive 1 were remarkably similar at all levels, and the same was true for Active 2 and Inactive 2 (the latter two differed from the former by a small seasonal change). As a result, the reasons for the fluctuations in eastern Pacific tropical cyclone activity appeared to lie with the time varying components, e.g., the waves.

TABLE 1. Dates (1991) and total number of tropical depressions, storms, and hurricanes for each period of interest.

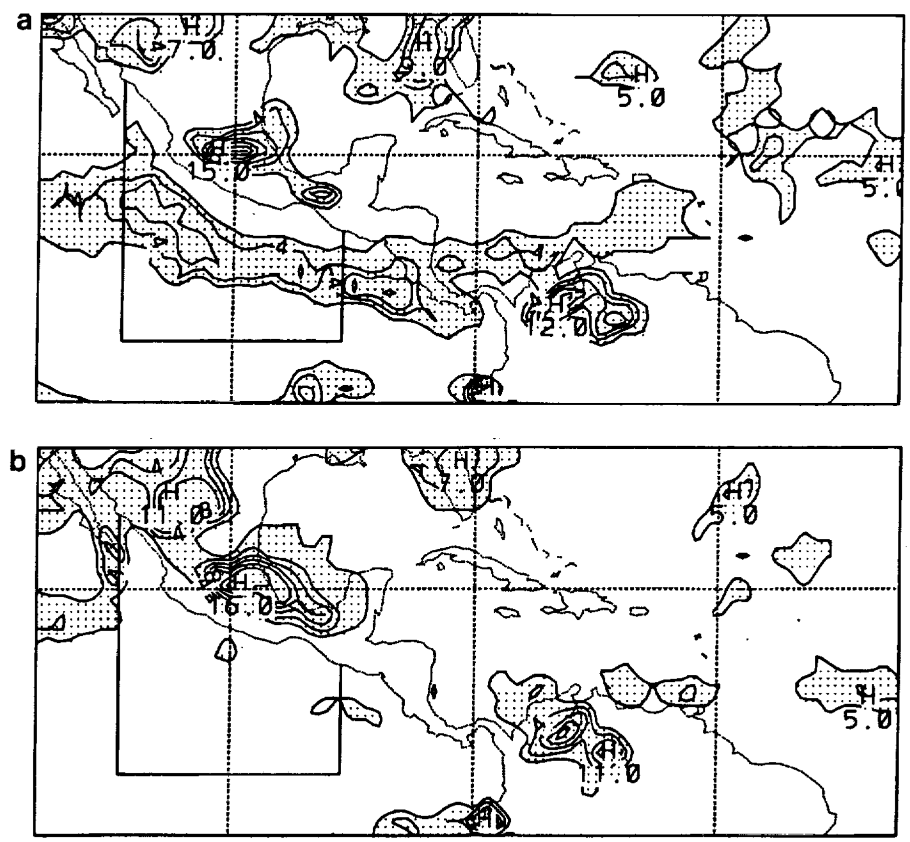
	DATE	STORMS
Active 1	6/15-6/27	4
Inactive 1	7/01-7/11	0
Active 2	7/29-8/10	3
Inactive 2	8/19-8/31	0

In an attempt to describe these transients, storm tracks during the various periods were identified using "vorticity frequency" diagrams. These are constructed simply by counting the number of observation times at each grid point during a given period that the relative vorticity exceeded a specified value. The resulting (integer) fields were contoured. The presence of a continuous swath of nonzero values was taken as representative of a storm track. Localized maxima also occurred that related to quasi-stationary regions of large vorticity. In the regions of interest, these were primarily associated with the presence of terrain.

Figure 2a shows the frequency of vorticity > 2 X 10^{-5} s^{-1} at 700 mb for Active 2. Several features stand out. Maxima in vorticity frequency occurred in the lee of the Guiana Highlands of Venezuela and in the vicinity of the Andes. A storm track was present from north of Venezuela westward across Nicaragua and into the eastern Pacific. Surprisingly, little evidence existed of a storm track east of South America, the direction from which easterly waves would be expected to come.

Figure 2b shows the vorticity frequency for Inactive 1 using the same critical value. Vorticity maxima were still found in the South American mountain region, but no evidence was present for a storm track westward from that region. Conversely, some evidence existed for a storm track from the east.

Figure 2. Number of occurrences at each grid point of relative vorticity exceeding 2 X 10^{-5} s^{-1} during (a) the second Active period and (b) the first Inactive period (see Table for dates). Contour increment: 2; only values greater than 2 are contoured.



The results from the other active and inactive periods (not shown) were remarkably similar to Figure 2. Several conclusions can be made. First, during active periods vorticity maxima associated with traveling waves reach the Central American mountains and pass into the Pacific, where they frequently spawn eastern Pacific tropical cyclones. Second, during inactive periods in the eastern Pacific, waves do not even reach Central America. Yet during these periods the South American mountains remain an active region of cyclonic vorticity generation. Third, there is little evidence for easterly wave activity in the Atlantic during active periods. Both the vorticity source over South America and the lack of easterly waves during active periods are new and unexpected results.

The interpretation of these results, however, is greatly clouded by the uncertainty in the input global analyses with regard to the presence of easterly waves. It is possible that fluctuation in easterly wave activity unseen by the numerical model is producing the fluctuations in eastern Pacific cyclogenesis. Alternatively, South American mountains might be the primary source of vorticity for Pacific storms, and the prevailing wisdom as to the need for easterly waves may be entirely incorrect. Finally, weak and difficult to locate easterly waves may be rejuvenated by interaction with vorticity maxima near South America, so that the combination of these features may be required for active eastern Pacific cyclogenesis.

With the current data sources we are not able to provide final answers to these questions. This is but one of many possible uses for Lidar winds over the tropical Atlantic. Because the waves in question are synoptic scale, they can be captured quite accurately by our previous analysis methods for high-altitude platforms. Alternatively for lower orbital altitudes, a global model with four-dimensional data assimilation on a six-hour cycle would likely make optimum use of Lidar winds for Atlantic easterly waves. Such assimilation cycles already are used and would require no substantial upgrading. Thus the study of easterly waves could be carried out over a wide range of platform altitude and laser power. Should the wind Lidar program be again funded, our research will focus in this area.

Finally, one additional factor makes the subtropical Atlantic outstanding for Lidar-wind studies: during the easterly wave season (Northern Hemisphere summer and fall), enormous amounts of dust are ejected from the African continent and frequently travel all the way across the Atlantic. The backscatter from this dust layer, which can easily be 4000 m deep, will provide detailed profiles of winds in the exact layers needed to study easterly waves, even from a modestly powered Lidar. The bottom line is that Lidar-derived winds would be an unprecedented and badly needed source of data for the Atlantic, and indeed global, subtropical region.

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13. ABSTRACT *(Maximum 200 words)*

The Laser Atmospheric Wind Sounder (LAWS) has recently been deselected from EOS. A broad range of orbital altitudes and laser power are being considered for future wind Lidar missions. As a result, as was anticipated in the proposed work, it may be impossible to meaningfully study tropical cyclones with Lidar wind data because data coverage (i.e., swath width) is insufficient. Research on this grant has focused on how to maximize the benefits of a wind Lidar regardless of the choice of platform or laser. Our studies have shown that major unsolved problems in tropical meteorology relate to the structure, dynamics, and role in tropical cyclogenesis of "easterly waves." These disturbances exist almost everywhere in the global subtropics. Results are described that focus upon easterly wave impacts on eastern Pacific tropical cyclogenesis. The availability of wind Lidar data would create tremendous opportunities for the study of these waves and their role in the general circulation.

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